'l'he Design of a Benign Fail-safe Mechanism Using a I.ow-melting-point Metal Alloy Coupler

Richard S. Blomquist

California Institute of Technology

Jet Propulsion Laboratory

September 6,1994

As part of the interface agreement between the alpha proton x-ray spectrometer (APXS) deployment mechanism (ADM) and the Mars Pathfinder rover, a fail-safe mechanism was promised to insure recovery from a failed actuator. Because the APXS sensor head is placed on Martian soil by the ADM, the rover is crippled if the actuator fails when the mechanism is in its deployed position, as rover clearance is then reduced to zero. The following paper describes the unique fail-safe mounted on the ADM, especially the use of a low-temperature-melting alloy as a coupler device,

Due to constraints on the rover and the design of the ADM, the fail-safe mechanism must be rotary in nature and provide 10 in-lbs of retraction torque. It must withstand 100 g's, 150 in-lbs of restraining torque, a temperature from -110° C to +70" C, and atmospheric pressures ranging from high vacuum to 760 torr. Furthermore, it must require no pyro firing and need less than 10 Watts and 10 minutes to operate in Mars ambient conditions (- 100° C, 10 Torr, CO_2). Finally, the fail-safe mechanism should weigh 20 to 30 grams, fit into a 1" x 2" x 2" volume, and be inexpensive.

Since pyrotechnics were out of the question, alternative release devices became prime candidates. Among those considered were wax pellet actuators, but their size, cost, and power consumption made them prohibitive. Another approach was a nitinol pin puller, with multiple strands pulling on the pin, However, due to friction imposed on the pin, the energy necessary to activate the nitinol wire and maintain adequate pulling margin exceeded the design limit, The final idea considered was a low-melting-point metal pellet coupler in parallel with a Negator spring pack. In its solid state, the metal rigidly connects the driver (the actuator) and the driven part (the mechanism), When commanded, a strip heater wrapped around the coupler melts the metal pellet, allowing the driven part to turn independent of the driver, The Negator spring retracts the mechanism to its fully stowed position. This concept meets all the design criteria, and provides an added benefit. When the metal hardens the coupler once again rigidly connects the actuator and the mechanism.

The concept of a metal alloy coupler originated with a metal in mind -- Cerrobend. This material typically is used in fusible links such as fire suppression sprinklers and as structural support during machining of thin-walled parts. The metal is melts at 60° C. During a fire, when the temperature reaches cerrobend melting temperature, the fusible link gives way and the sprinklers turn on. With the material chosen, the remaining design issues were the coupler housing design, the drive shaft, choice of a heating element, and thermal isolation.

The coupler housing must be thermally conductive, so aluminum was chosen. It must also be able to withstand 150 in-lbs when filled with Cerrobend. Its shape should keep the Cerrobend pellet from turning inside and from deforming under load, After initial testing, a cylindrical shape was found to be inadequate, as the pellet rotated with the driver shaft at about 25 in-lbs. In fact, as the adhesive forces of melted cerrobend are quite similar to liquid mercury, wall shear could not be counted on to keep the pellet from turning. Therefore, an elliptical shape was tried next, with complete success.

The smooth ellipse made it possible to effectively mount a strip heater around the coupler housing using RTV66, a silicone adhesive rated for cold temperature use. Although RTV66 does not conduct that well, it was used because only a very thin layer is required for adequate bonding. As an added safety feature, shrink wrap is placed over the strip heater to redundantly keep it in place

The driver was shaped to increase shear area between the driver and the Cerrobend. A cross section in the shape of a plus sign (+), provides enough area to meet the design criteria, even though the shear strength of Cerrobend is approximately 3600 psi.

Once assembled , the driver connects to the mechanism via a titanium shaft (see Figure 1). Titanium was chosen because of its high strength to weight ratio and because of its poor thermal conductance. The coupler mounts onto the front link of the deployment mechanism, which is also made of titanium, As shown in Figure 1, a felt spacer between the coupler and the front link provides more thermal conduction isolation and a felt booty wrapped around the coupler housing virtually eliminates radiative losses in the coupler,

Results of testing show that in a Martian environment of -95° C and 10 torr CO_2 atmosphere, approximately five minutes are necessary to actuate the fail-safe mechanism when 6.75 Watts of power are provided, A graph of typical cerrobend temperature vs. heating time is shown in Figure 2. Furthermore, in these cold conditions, the fail-safe coupler never allows full release of the mechanism, but rather slowly retracts the mechanism. Torque tests at Earth ambient conditions show that the fail-safe coupler can withstand $\geq$ 150 in-lbs of torque with no slipping.

Multiple actuations of the fail-safe mechanism show, however, that withholding torque and actuation time both go down, due to incomplete setting of the drive shaft in the Cerrobend.

The concept presented here can easily be applied to other applications. For example, spring-loaded pin puller/pusher devices can use Cerrobend pellets to hold the pins in place before actuation. Also, electrical disconnect mechanisms can disconnect wires via a spring-loaded Cerrobend spreader, Anywhere release devices are needed low-melting-point couplers can be considered. The issues to be concerned with are thermal isolation, proper setting of the parts before actuation, and possible outgassing concerns. However, when these issues are overcome, the resulting release mechanism can promise to be the most light, simple, power conserving alternative available.

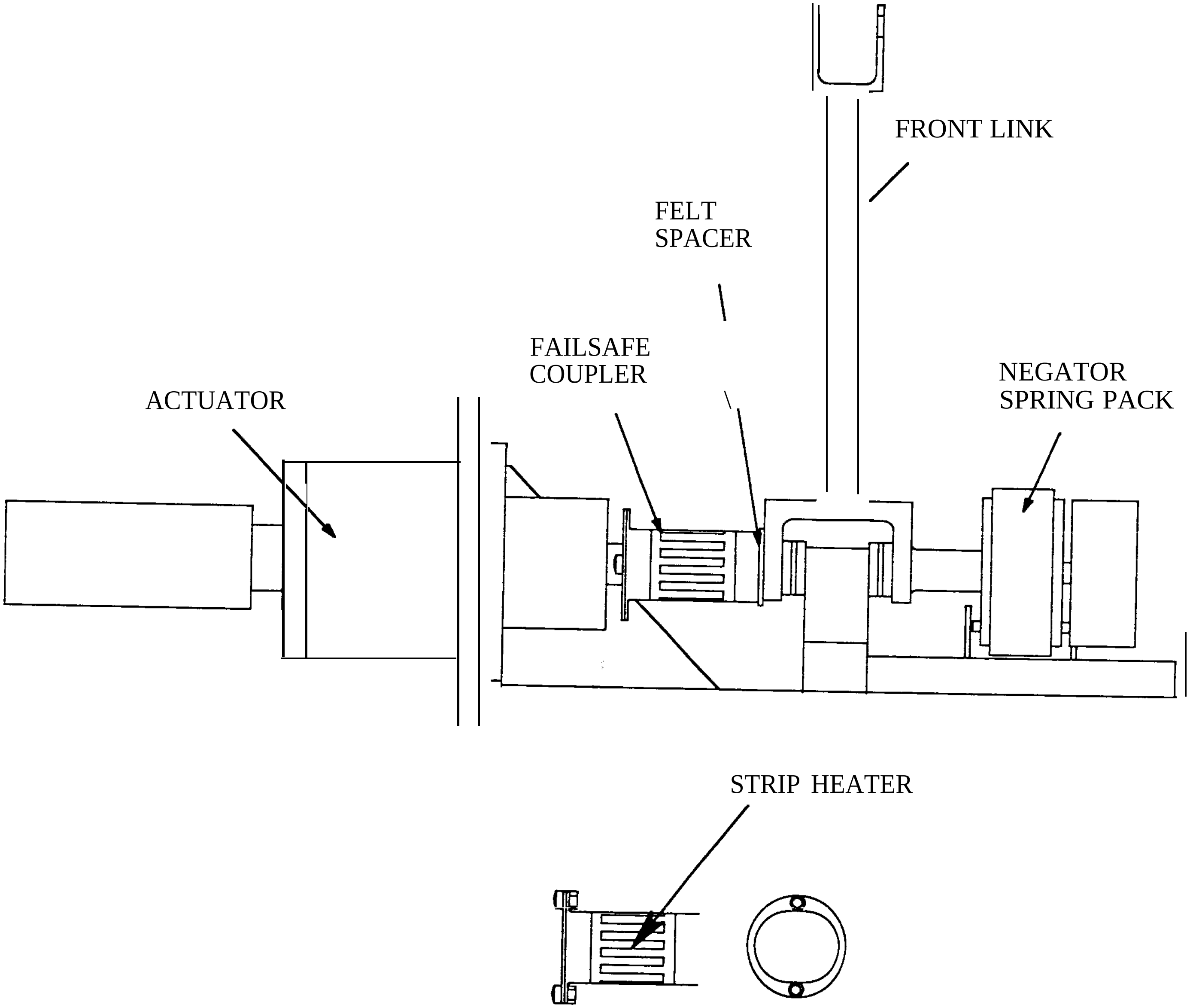

FIGURE 1. LAYOUT OF FAILSAFE MECHANISM INTEGRATED ONTO ADM.

FIGURE 2. TEMPERATURE CLIMB OF CERROBEND COUPLER VS TIME